

Numeracy and Risk Literacy: What Have We Learned so Far?

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Abstract. Numerical skills are essential to make informed decisions in our daily life. Unfortunately, many people lack basic numeracy, which limits their ability to accurately interpret risks (i.e., risk literacy). In this paper, we provide an overview of research investigating the role of numeracy in two prominent domains, where most research was concentrated, health and finance. We summarize what has been learned so far in these domains and suggest promising venues for future research. We conclude that it is important to conduct interventions to improve numeracy in less numerate individuals and to help them make informed decisions and achieve better life outcomes.

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Imagine that your lifetime risk of developing bowel cancer is about 1 in 23. Now imagine that regularly undergoing screening can reduce this risk by 40%. However, the screening might occasionally result in bowel perforation, which is a dangerous condition and the risk of this happening is 2%. In addition, you need to pay for it and it would increase your annual health spending with about 80 Euros. Would you get screened regularly? Can you afford it? Is it worth it?

This example illustrates one of the many decisions that people regularly face in which numerical information is abundant and outcomes are uncertain. It also illustrates that in order to make informed decisions, it is now more important than ever to have adequate numerical skills or *numeracy*—i.e., the ability to understand and use numbers, perform arithmetic operations and compare numerical magnitudes (Ancker & Kaufman, 2007; Cokely, Galesic,

Schulz, Ghazal, & García-Retamero, 2012; Fagerlin, Ubel, Smith, & Zikmund-Fisher, 2007; Peters, 2012). In addition, being able to compute proportions, percentages, or probabilities—often referred to as *statistical numeracy* (Cokely, Ghazal, & García-Retamero, 2014)—is especially important when decisions involve risk and uncertainty, as is often the case in the domains of health and finance; and it is fundamental for *risk literacy*—one’s practical ability to evaluate and understand risk in the service of skilled and informed decision making (Cokely et al., 2018).

In the past twenty years, since the publication of the first brief statistical numeracy test by Schwartz and colleagues (Schwartz, Woloshin, Black, & Welch, 1997), an increasing amount of research has addressed the importance of numeracy across a variety of contexts (see Reyna, Nelson, Han, & Dieckman, 2009 for a review). Overall, this research has shown that low numeracy is pervasive and generally associated with disadvantageous outcomes. Here we give a brief, illustrative overview of research investigating the role of numeracy in two prominent domains, where most research was concentrated, health and finance. Rather than being exhaustive, our goal is to summarize what has been learned so far and suggest promising venues for future research. The studies reviewed here concern mostly, though not exclusively, statistical numeracy. In the first section, we illustrate the prevalence of low

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numeracy, and its implications for decisions about health and health outcomes. In the second section, focusing on studies from the financial domain, we illustrate the underlying mechanisms that drive the effects of numeracy on financial decisions and outcomes. Finally, we discuss the urgent need for interventions that can demonstrate how we can use numeracy to help people make informed decisions and achieve better life outcomes. Important aspects that are not broadly covered in the current review but might be of interest to readers are relevant theoretical models (e.g., the skilled decision theory, Cokely et al., 2018; and the fuzzy trace theory, Broniatowski & Reyna, 2017), recommendations regarding the measurement of numeracy and the available instruments (see Cokely et al., 2014), and the components of numeracy and their distinct roles in the decision making process (see Peters & Bjälkebring, 2015).

Influence of numeracy on health

Numerical skills are essential for navigating in the modern health care environment. To illustrate, physicians often need to interpret and communicate information about the benefits and risks of different medical treatments, screenings, and lifestyle choices (Anderson & Schulkin, 2014), and patients need to understand and use this information to consent on their own behalf to medical treatment and to adhere to medical advice (Zikmund-Fisher, Mayman, & Fagerlin, 2014).

Most of the research investigating numerical skills in patients used an 11-question test developed by Schwartz et al. (1997) and Lipkus, Samsa, and Rimer (2001). The test specifically assesses practical knowledge of basic probabilistic concepts and mathematical operations, including comparing risk magnitudes, converting percentages to proportions out of one, converting proportions to percentages, converting probabilities to proportions out of one, and computing probabilities. Examples of items from the test are “Which of the following numbers represents the biggest risk of getting a disease? 1 in 10, 1 in 100, or 1 in 1,000?” and “If the chance of getting a disease is 20 out of 100, this would be the same as having a ___% chance of getting the disease.” Unfortunately research using this test showed that many patients do not have the skills necessary for accurate, unaided evaluation of risks (Cokely, Ghazak, Galesic, García-Retamero, & Schulz, 2012; García-Retamero & Galesic, 2013). For instance, Rodríguez et al. (2013) showed that more than 40% of the patients in the US incorrectly answered most of these items developed by Schwartz et al. (1997) and Lipkus et al. (2001) described above (see also Gaissmaier et al., 2018). This research converges with other studies conducted on general

community samples (Galesic & García-Retamero, 2010; Kutner, Greenburg, Jin, & Paulsen, 2006; Lipkus et al., 2001), indicating the common struggles people often have with basic numerical concepts: Many people do not possess basic, practical mathematical skills that are often essential for independent risk evaluation and general skilled decision making in the context of health.

Previous research also showed that numeracy is one of the best predictors of important outcomes in health and medical decision making. García-Retamero and Cokely (2017) conducted a systematic review and an analysis of the available literature on this topic. The authors concluded that numeracy is robustly related to (a) the accuracy of perceptions of health-related benefits and risks in patients; (b) the quality of medical decision making and shared decision making between doctors and patients, and (c) health outcomes in patients.

Patients with low numeracy often have less accurate perceptions of the benefits and risks of medical treatments and interventions. Compared with patients with high numeracy, less numerate patients overestimate their personal risk of suffering several diseases (Davids, Schapira, McAuliffe, & Nattinger, 2004; Gurmankin, Baron, & Armstrong, 2004), and they overestimate the efficacy of uncertain treatments (Weinfurt et al., 2003). Patients with low numeracy also have more difficulty interpreting the risks of side effects (Gardner, McMillan, Raynor, Woolf, & Knapp, 2011) and understanding the information necessary to follow dietary recommendations (Rothman et al., 2006). Patients with low numeracy also make less accurate diagnostic inferences based on numerical information about screening (García-Retamero, Cokely, & Hoffrage, 2015; García-Retamero & Hoffrage, 2013; Gigerenzer, Gaissmaier, Kurz-Milcke, Schwartz, & Woloshin, 2007; Petrova, García-Retamero, Catena, & van der Pligt, 2016) and are less able to use this diagnostic information to adjust their risk estimates (Schwartz et al., 1997). Research on the underlying mechanisms shows that people with low numeracy have difficulties reasoning about the underlying relationships in the data (Johnson & Tubau, 2017) and do no benefit from interventions that clarify the causal structure of the data (McNair & Feeney, 2015). Finally, less numerate patients are more easily biased by the way health-related numerical information is framed (García-Retamero & Galesic, 2009, 2010, 2011; Peters & Levin, 2008; Peters et al., 2006). This inaccuracy of perceptions of health-related benefits and risks may cascade, thereby influencing patients' efforts to promote health and prevent disease, and efforts to comply with diagnosis and treatment directives (Paasche-Orlow & Wolf, 2007; von Wagner, Steptoe, Wolf, & Wardle, 2009).

Numeracy also affects the quality of medical decision making, which may influence shared decision making.

Compared with patients with high numeracy, less numerate patients often make less accurate decisions based on numerical information about screening and the risk of suffering a disease (García-Retamero & Cokely, 2014; Petrova et al., 2016). For instance, many patients with low numeracy would go through screening when the test does not show benefits. Physicians' levels of numeracy can also influence the quality of patients' decisions as less numerate physicians often offer lower quality risk communication to their patients (e.g., they are less likely to mention risks of important harms of screenings; Petrova, Kostopoulou, Delaney, Cokely, & García-Retamero, 2017).

Less numerate patients also tend to favor a paternalistic model of medical decision making, in which doctors are dominant and autonomous and make decisions on their patients' behalf (García-Retamero, Wicki, Cokely, & Hanson, 2014), whereas patients prefer not to participate and instead delegate decision making (Galesic & García-Retamero, 2011). This finding is troubling given that the paternalistic model of medical decision making has well-documented ethical and practical limitations (e.g., it prevents or limits patients' ability for self-determination) (Kaplan & Frosch, 2005). Accordingly, patients with low numeracy are more likely to report negative interactions with their doctors (Manganello & Clayman, 2011; Roter, 2005), which influence their subsequent information search and their ability to engage in decision making (McCaffery, Smith, & Wolf, 2010). For instance, less numerate patients often avoid asking doctors questions about their symptoms and medical treatments (Paasche-Orlow & Wolf, 2007), they tend to spend less time gathering information about their disease during medical sessions (Portnoy, Roter, & Erby, 2010), and they rarely use personal health records on the Internet (Sharit et al., 2014).

Results in accuracy of perceptions and quality of medical decision making often translate into important health outcomes, including disease management, quality of life, risk of hospitalization and prevalence of comorbidity. For instance, low levels of numeracy predict patients' difficulty following a complex dosing regimen (Estrada, Martin-Hryniewicz, Collins, Byrd, & Peek, 2004; Waldrop-Valverde, Jones, Gould, Kumar, & Ownby, 2010), their total body mass index (Huizinga, Beech, Cavanaugh, Elasy, & Rothman, 2008), and their activity limitations as well as struggles with emotional functioning (Apter et al., 2009). Low levels of numeracy also predict more frequent utilization of emergency department services (Apter et al., 2006; Ginde, Clark, Goldstein, & Camargo, 2008) and longer delays when seeking medical attention, which can dramatically increase patients' risk for death and major disability (Petrova et al., 2017).

Compared with patients with more developed numerical skills, less numerate patients are also at greater risk for comorbid conditions, including myocardial infarction, chronic obstructive pulmonary disease, peptic ulcer disease, liver disease, diabetes, and HIV/AIDS (García-Retamero, Andrade, Sharit, & Ruiz, 2015; Petrova et al., 2017). On average, the relative risk that patients with low numeracy suffer one of these diseases is roughly 40% greater than that of patients with high numeracy. Patients with low numeracy also take 20% more prescribed medication than those with higher numerical skills (García-Retamero et al., 2015). These findings hold statistically after controlling for the effect of key demographics (e.g., age, education, ethnicity, and household income) and body mass index, suggesting that numeracy has a unique relationship with health outcomes above and beyond the effect of these factors.

In summary, there is a large and consistent body of research in health and medical decision making showing that many people have problems understanding health-relevant numerical expressions of probability about health. This research indicates that many people are functionally innumerate, making them vulnerable to health problems regardless of other protective factors. In contrast, people who have well developed numerical skills tend to have more accurate perceptions of health-related benefits and risks, and often make better decisions that translate into important health benefits (e.g., lower prevalence of comorbidity).

Influence of numeracy on financial decision making

A great body of evidence accumulated in the last decade has also shown that statistical numeracy is one of the strongest unique predictors of superior decision making in the financial domain (e.g., Estrada-Mejía, de Vries, & Zeelenberg, 2016; Ghazal, Cokely, & García-Retamero, 2014; Pachur & Galesic, 2013; Petrova, van der Pligt, & García-Retamero, 2014; Traczyk, Lenda, et al., 2018; Traczyk, Sobkow, et al., 2018; Traczyk & Fulawka, 2016). Numeracy helps make better decisions in paradigmatic risk tasks (e.g., risky prospect evaluation) tested in laboratory settings; numeracy is also crucial to real-life financial decision making measured outside the lab by objective economic variables. In this section, we focus on studies that demonstrated the role of numeracy in basic financial paradigmatic risk tasks, discussing possible moderators and cognitive mechanisms that are likely to explain better performance of more numerate people in financial tasks. Next, we present some recent findings showing that effects of numeracy on financial decisions are not limited to simple monetary lotteries, but can be also observed "in the wild" explaining economic and societal outcomes.

The role of numeracy in paradigmatic risk tasks

In economic theory, optimal behavior under risk and uncertainty is defined by variants of expected value or expected utility models (Starmer, 2000). For instance, expected utility theory (von Neumann & Morgenstern, 1944) posits that a rational decision maker selects alternatives that maximize expected utility—"a measure of extent of goal achievement" (Baron, 2008, p. 233). In the financial domain, this goal is often realized by gaining more money and can be accomplished by following the rule of expected value/utility maximization. That is, if a person considers whether to choose lower but sure 5 EUR payoff or higher but uncertain 20 EUR payoff that can be obtained with a probability of 50% (otherwise nothing), she should compare these two alternatives and select the one that has higher expected value/utility (i.e., $100\% * u(5 \text{ EUR})$ vs. $50\% * u(20 \text{ EUR}) + 50\% * u(0 \text{ EUR})$). The expected utility model and its alternatives provide a benchmark for normatively superior decisions and are often used for prescriptive reasons. However, their descriptive function (e.g., how good expected utility models are in predicting real behavior) is often debated.

Research has repeatedly demonstrated that the classical expected utility model fails to accurately describe choices (Gilovich, Griffin, & Kahneman, 2002). People do not follow the assumptions of normative theory. Instead, their behavior under risk and uncertainty tends to be inconsistent, driven by factors irrelevant to the decision problem and restricted by their cognitive limitations as well as the complexity of the task (Simon, 1990). When it comes to the role of numeracy, the main question that arises here is whether more numerate people are more likely to make better financial choices because they adhere to the assumptions of normative theory; alternatively, they rather employ other strategies and processes that may be not always coincide with the normative predictions but enable them to make adaptive choices taking into account the structure of the task and environment. In other words, we address the question of whether superior decisions made by people with high numeracy are preceded by complex cognitive computations (e.g., calculation of EV (expected value)) that lead to a comparison of EV/utilities or rather result from different operations.

This interesting question was tackled by Cokely and Kelley (2009). In their study, participants completed the test developed by Schwartz et al. (1997) and Lipkus et al. (2001) described above and were presented with 40 choice problems under risk. This paradigmatic task consisted of a series of simple monetary lotteries in which participants had to choose between a certain and risky option each time. To illustrate, in a sample trial a lottery of '\$50 for certain vs. 50% chance to gain

\$400' was displayed to participants and their task was to select the option they preferred. In this example, the EV of the certain option was \$50 and the EV of the risky option was \$200 (i.e., $50\% * \$400$); like in this example, a normatively superior option existed in each of the 40 choice problems. Importantly, the process of making a choice was traced by recording retrospective verbal reports after each decision. That is, participants were asked to report the exact thoughts and reasons that they considered when making their choice. Based on this measure, the authors were able to analyze both performance in a risky task and an introspectively-identified cognitive process that preceded it. The results of this study demonstrated that higher numeracy was related to more choices maximizing EV and more frequent verbalization of EV computations. Importantly, it was also related to more frequent verbalization of other considerations such as transforming probabilities (e.g., converting a 66% probability of success into a 34% probability of failure; translating percentages into frequencies and vice versa), considering and comparing different gains, losses, and their probabilities. In a mediation analysis the relationship between higher numeracy and more choices maximizing EV was fully explained by what the authors referred to as *elaborative heuristic search* – "more thorough exploration and representation of the problem space" (Cokely & Kelley, 2009, p. 22)¹. That is, people with high numeracy, besides explicit EV computations which require multiplication and addition, considered more aspects of the decision problem, recoded the given probabilities, focused on maximum and minimum differences between outcomes, or took into account their risk preferences. To conclude, this study demonstrated that more numerate people exhibit superior performance not only because they calculate EV but also because they are more likely to engage in elaborative processing of numerical information describing the choice problem.

If people with high numeracy do not simply compute EV but rather base their choices on heuristic processing, maybe they are able to perform such operations faster than people with low numeracy? This problem was investigated in a study by Ghazal et al. (2014). The authors asked participants to make a binary choice on three problems in a financial context (e.g., whether they would prefer 100 EUR for certain or 75% chance of 200 EUR). Along with choice responses, the authors recorded response latency—i.e., the amount of time from the presentation of the problem to the participant's decision. Two main findings emerged from this study.

¹Elaborative heuristic search was operationalized as "the total number of different types of simple considerations verbalized (excluding expected-value calculations and ambiguous codes)" (Cokely & Kelley, 2009, p. 22)

First, people with high numeracy were more likely to select the normatively superior options. Second, the relationship between superior performance in the financial task and numeracy was mediated by decision latency. That is, people with high numeracy deliberated more on the decision problems (i.e., spent more time making a choice) which in turn led to more normatively superior decisions. Taken together, the authors concluded that better financial decisions made by more numerate people may result from metacognitive processes that are captured by longer deliberation. That is, more numerate people were also more accurate in evaluating their decisions—they made more accurate judgments on the accuracy on their judgments (Ghazal et al., 2014), however these effects were tested only in the medical domain. In reference to results reported above, longer deliberation likely results from elaborative heuristic processing rather than cognitive processes associated with EV maximization.

The two psychological mechanisms described above (i.e., elaborative heuristic processing and metacognitive processing) may explain a wide range of experimental effects showing superior performance of more numerate people in financial tasks. For example, it has been demonstrated that people with high numeracy are more consistent in their risk preference (Ashby, 2017), more sensitive to variations in EVs (Jasper, Bhattacharya, Levin, Jones, & Bossard, 2013), and less prone to framing effects and the influence of irrelevant information (Johnson & Tubau, 2013; Peters & Levin, 2008). Their pricing of monetary gambles is closer to expected values (Millroth & Juslin, 2015), which is reflected in more linear utility function (Schley & Peters, 2014) and less distorted probability weighting (Patalano, Saltiel, Machlin, & Barth, 2015). Intriguingly, people with high numeracy seem to be flexible in employing choice strategies depending on the task structure and decision environment (Traczyk, Sobkow, et al., 2018). That is, they adaptively select choice strategies and maximize EV when problems are meaningful and lead to substantially higher payoffs. In contrast, in case of trivial choice problems, in which payoffs are similar, they switch to faster and less effortful heuristic strategy.

An interesting line of research also links numeracy and financial decision making to emotions (Peters, 2012). In particular, several studies indicated that more numerate people are able to derive more precise “affective meaning” from numbers—the clarity of affective reaction to numbers in such people is more precise—which subsequently guides their judgments and choices (Peters et al., 2006). In other words, more numerate people seem to be more sensitive to affect that is directly related to a decision problem and they use this information in the decision-making process.

A greater sensitivity to numbers in more numerate people was also demonstrated in a study that employed a lab-based experimental insurance task (Petrova et al., 2014). Participants were randomly assigned to one of the three conditions. In each condition, they were asked to visualize that they owned a camera, the current market value of which was 500 EUR. Then, they were asked to indicate how much they would pay for insurance against loss or theft of the camera given a probability of loss (1%, 5%, 10%, 25%, 50%, 75%, 90%, 95%, 99% as a within-subjects factor). In the *neutral* condition, participants were presented with a common description of the camera (i.e., as it is presented in a web store). In the *affective* condition, a description of the camera was more affect-rich and highlighted that the camera was a birthday gift from a grandfather. Finally, in the *reappraisal* condition, the camera was described in the same way as in the affective condition but participants were asked to write down how they would cope with negative consequences of a potential loss or theft. The results showed that people were the most sensitive to changes in probability (of loss/theft of the camera) in the reappraisal condition, while in the affective condition they distorted probabilities to a greater extent. This effect was present among more numerate people. Furthermore, numeracy was also related to higher variance in reported emotions of hope and fear, which predicted higher sensitivity to changes in the probability scale. Accordingly, people with high numeracy experienced more differentiated emotional reactions to probabilities which resulted in higher sensitivity to probabilities and less distorted probability weighting.

Additional studies investigating the relationships between numeracy, affect, and probability weighting indicated that more numerate people are likely to use affect as information depending on its source. For example, Traczyk and Fulawka (2016) used a modified insurance task (described above) to investigate the influence of incidental affect (i.e., affect irrelevant to the decision problem) on probability weighting. Instead of manipulating the affective description of a camera, each insurance decision was preceded by a presentation of unrelated negative or neutral pictures. The results of this study showed that negative affect induced by the pictures influenced sensitivity to changes in probability but only among participants with low numeracy, who were more prone to the impact of incidental and irrelevant affect.

To summarize, several studies demonstrated that the role of numeracy in financial decision making goes beyond calculations. More numerate people seem to deliberate more on decision problems by engaging in elaborative heuristic processing. Interestingly, higher numeracy helps construct an affectively-charged representation of the problem. In this sense, people with

higher numeracy are able to extract more affective information from numbers that are relevant to their choices and, at the same time, they are less prone to incidental affect that is irrelevant in the decision-making process.

The role of numeracy in real-life financial decision making

Numeracy is a powerful predictor of better decisions not only in paradigmatic risk tasks, but also in real-life financial decisions. Let us think about the following situations: Choosing a credit card, insurance, mortgage, taking a loan, investing in stocks, gambling, etc. Making good decisions in all of these situations requires knowledge about financial concepts (i.e., financial literacy; Fernandes, Lynch, & Netemeyer, 2014) as well as the ability to understand and perform number-related complex operations (i.e., numeracy). Nevertheless, a substantial number of individuals living across different countries experience serious difficulties in making good financial decisions. Importantly, these difficulties are not limited to complex financial problems only, but are apparent in what must be simple everyday financial decisions.

To illustrate, a recent analysis using data from the Program for International Assessment of Adult Competencies (Bhutoria, Jerrim, & Vignoles, 2018) conducted by the Organization for Economic Cooperation and Development (OECD) on nationally representative samples of adults in 31 countries revealed serious errors that people make in everyday financial decisions. For instance, one out of three respondents from Spain experienced difficulties in calculating a change during usual shopping or in calculating a price of a product given 'per unit' (e.g., per kilo) cost. Moreover, about two thirds of participants misunderstood simple financial graphs. Crucially, average performance across countries in these simple financial tasks predicted national wealth (the per capita Gross Domestic Product, GDP) and explained from 16 to 27 percent of GDP variance. The authors of this report concluded that a substantial number of people (even those living in developed OECD countries) do not have basic skills that are required in real-life financial tasks. They also stress a strong and urgent need for policy intervention to help people become more financially literate.

Financial literacy is usually measured using tasks that require understanding financial concepts (e.g. "Do you think that the following statement is true or false? 'Bonds are normally riskier than stocks.'") or solving financial tasks (e.g., "Suppose you have \$100 in a savings account and the interest rate is 20% per year and you never withdraw money or interest payments. After 5 years, how much would you have in this account in total?"). These measures predict a wide range of financial

behaviors such as having an emergency fund, credit and checking fees, positive savings, etc. (Fernandes et al., 2014). However, these relationships became weaker or even insignificant when controlling for cognitive variables (e.g., numeracy, consumer confidence investing, planning for money, willingness to take investment risks) suggesting the presence of omitted important cognitive variables in many studies on financial literacy. A recent study of Skagerlund, Lind, Strömbäck, Tinghög, and Västfjäll (2018) suggests that numeracy provides the 'computational engine' behind financial operations and as a result can be the central component of this construct. In this study conducted on a representative sample of the general Swedish population, Skagerlund et al. (2018) found that objective numeracy was the strongest predictor of financial literacy, even when controlling for demographics (e.g., age, gender, education, income) and cognitive and emotional factors (e.g., cognitive reflection, self-efficacy, mathematics, and financial anxiety).

The importance of numeracy for real-life financial outcomes was particularly evidenced in a study by Estrada-Mejia et al., 2016. Based on a large sample of Dutch adults, they found a significant correlation between numeracy and personal wealth. Wealth was calculated on the basis of declared assets and liabilities (e.g., saving accounts, stocks, bonds, real estate, mortgages, loans, credits). Authors estimated that on average a one-point increase in numeracy (Lipkus et al., 2001) was associated with 5 percent more personal wealth. The effect of numeracy was similar in magnitude to the effects of income or having a university degree. Moreover, the relationship between numeracy and wealth was significant even when other measures (e.g., differences in education, risk preferences, financial knowledge, seeking financial advice, beliefs about future income or need for cognition) were factored out, indicating that numeracy is a robust and independent predictor of personal wealth. Moreover, numeracy was found to be a key determinant of wealth accumulation over time. During a 5-year period people with low numeracy tended to decumulate wealth while those with high numeracy had a similar level of wealth.

Altogether, results of the abovementioned studies indicate that numerical abilities are crucial not only for individuals (those with higher numeracy tend to be more financially literate and accumulate more personal wealth over time), but also for society and economics (numerical abilities in the population are associated with national wealth).

Interventions: How to improve numeracy and informed decision making?

Despite a bulk of empirical research showing the predictive power of numeracy in the medical and financial

domains, evidence on the effectiveness of trainings or education programs aimed at improving numeracy and informed decision making is scarce.

The widely shared intuition is that financial education programs could effectively improve real-life financial decision making. However, a meta-analysis conducted by Fernandes et al. (2014) revealed that this effect is minor and vanishes after few months. Moreover, people with low income, who should be the main target of these programs, benefit the least. These disappointing results indicate the need for complementary or alternative psychological methods that could help improve decision making, especially in people with low numeracy and/or low income.

Currently, we can observe a growing market of 'brain-training' companies offering cognitive trainings that one could perform using a personal computer or a smart phone. This trend aimed at improving brain and cognitive functioning seems to be very promising. However, a recent review by Simons et al. (2016) stressed the need for developing standards in designing these interventions and conducting research validating their effectiveness (such as introducing experimental designs with an appropriate active control condition). Moreover, Simons et al. (2016) suggested that brain-training interventions improve performance in trained tasks, but there is little evidence for transfer effects—i.e., improvement in other cognitive tasks or daily life measures. For example, a recent study by Kable et al. (2017) revealed that one of the most popular commercial training programs (ten weeks of games designed to enhance executive functions such as working memory, problem solving, or speed) was ineffective at improving performance and altering neural activity in decision tasks regarding delay discounting or risky choices (i.e., financial lotteries).

Having in mind the results reviewed so far, we argue that interventions aiming to improve numeracy hold promise for improving decision making across diverse contexts. One of the first studies testing this proposition was conducted by Peters and colleagues (Peters et al., 2017). In a longitudinal experiment, students enrolled in a statistics course were randomly assigned to one of two experimental conditions: Value affirmation manipulation vs. control. In the experimental condition, participants ranked six values (religion, knowledge, relationships, etc.) by personal importance and indicated why their most important value is important and meaningful to them. This manipulation was intended to change perception of statistics classes and to make students benefit more from this course. Results showed that subjective numeracy (i.e., a self-reported measure of how people perceive their numerical ability) declined over time in the control condition, whereas in the experimental condition it remained stable. In addition, the

combination of statistical education and value affirmation improved objective numeracy (i.e., a math test-based measure of how people perform with numbers and number operations). Interestingly, the authors also observed a significant indirect-only effect of the intervention via subjective and objective numeracy on financial outcomes, financial literacy and health behaviors what suggests possible transfer of increased numeracy to real-life outcomes.

Besides value affirmation, an alternative approach to improve numeracy could aim at a more basic and evolutionarily old mechanism related to the approximate number system. The ability to exactly perceive and manipulate numerosities as well as map symbolic numbers to magnitudes seems to be the precursor of objective numerical skills (Peters & Bjälkebring, 2015). Previous research demonstrated that trainings of the approximate number system (Park & Brannon, 2013) or mental number line (Kucian et al., 2011) transfers into performance on symbolic arithmetic tasks. However, up to date there is no scientific evidence for such types of training on numeracy and/or decision-making, so this approach yet promising demands further investigation.

In summary, scientific research has not provided the golden standard or a well-documented evidence-based intervention improving numeracy and decision making. However, previous research shows that this approach is promising. One of the greatest challenges facing researchers and policy makers would be to develop, test, and implement such interventions or programs that could be helpful for many vulnerable individuals and society in general. Another option would be the use of powerful, simple interventions such as visual aids and analogies that can have substantial benefits at minimal costs, particularly when designed to serve vulnerable populations with limited numeracy (Galesic & García-Retamero, 2013; García-Retamero & Cokely, 2013, 2017). These interventions robustly improve risk understanding in diverse individuals by encouraging thorough deliberation, enhancing cognitive self-assessment, and reducing conceptual biases in memory.

Finally, in this review we have focused on the benefits of high vs. low numeracy for decision making. However, whereas high numeracy can certainly help improve understanding and decision making, it will not be a panacea for all problems. For instance, information that is presented in a non-transparent way can mislead and confuse even those with high numeracy (García-Retamero & Cokely, 2017). In addition, there are problems that are notoriously difficult to solve even when presented transparently. One example is problems that require Bayesian inference such as deducing the probability of having a medical condition given a positive screening test. Although people with high numeracy are generally better at solving these problems, high

numeracy alone is likely to be insufficient to promote optimal choices under all conditions (see e.g., Chapman & Liu, 2009; Johnson & Tubau, 2013). This suggests that interventions and training directed at improving specific types of decisions are likely to be more successful if they also consider the context and the structure of decision problems, besides the numerical abilities of the recipients.

A large body of research from all over the world has demonstrated that low numeracy is important for a variety of health and financial outcomes. Studies with diverse samples show that low numeracy is prevalent in general population samples and found even in samples of highly qualified professionals (García-Retamero, Cokely, Wicki, & Joeris, 2016). In this review, we have illustrated that compared to people with low numeracy, people with high numeracy are at lower risk of negative outcomes such as disease or financial loss. Importantly, research points that the main reason for this advantage is superior decision making. Decision strategies reflected in the exploration of the decision space, processing of numerical information, and weighing and “feeling” decision options are some of the mechanisms that can explain the effects of numeracy on decisions and outcomes. These emerging research lines show that numeracy goes beyond calculations and computations of proportions (Peters, 2012) and that numeracy tests successfully capture the skills necessary for effective naturalistic decision making (e.g., more successfully than traditionally used fluid intelligence tests, see Cokely et al., 2018). Despite the overwhelming evidence on the importance of numeracy, interventions aiming to improve statistical numeracy and thus produce lasting and transferable improvements in decision making are still scarce and further research on mechanisms is needed to inform the design of such interventions. We also believe that the time has come to attempt a quantitative synthesis (i.e., meta-analysis) on the effects of numeracy on different aspects of decision making such as perceptions or choice. These ventures can bring us closer to reducing the gap between more and less numerate people, giving the latter ones an equal opportunity to be autonomous and informed citizens of the modern world.

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